

**Establishment of an Environmental Control Technology Laboratory
with a Circulating Fluidized-Bed Combustion System**

Quarterly Technical Progress Report

January 1 – March 31, 2004

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ABSTRACT

The purpose of this report is to present the progress made on the project “Establishment of an Environmental Control Technology Laboratory with a Circulating Fluidized-Bed Combustion (CFBC) System” during the quarter January – March 2004. The following tasks have been completed. First, plans for the renovation of space for a new Combustion Laboratory for the CFBC Facility have progressed smoothly. Second, the design calculations, including the mass balances, energy balances, heat transfer, and strength calculations have been completed. Third, considerable modifications have been made on the draft design of the CFBC Facility based on discussions conducted during the project kick-off meeting held on January 13, 2004 at the National Energy Technology Laboratory (NETL). Comments received from various experts were also used to improve the design. Finally, the drawings of all assembly parts have been completed in order to develop specifications for the fabrication of individual parts. At the same time, the proposed work for the next quarter has been outlined in this report.

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1. EXECUTIVE SUMMARY

This project, “Establishment an Environmental Control Technology Laboratory with a Circulating Fluidized-Bed Combustion (CFBC) System,” focuses on constructing a multi-functional circulating fluidized-bed combustion facility to investigate and control air pollutant emissions. Therefore, the primary goals in this current stage are to construct a new combustion laboratory and build this multi-functional CFBC Facility. Based on the work completed during the first quarter (September – December 2003) of the project, progress on the construction of a new Combustion Laboratory and the design of CFBC Facility have moved forward continuously.

The purpose of this report is to summarize the progress made on this project in the second quarter. The primary achievements during this period have been realized in the following areas. First, the construction of the new Combustion Laboratory has moved forward on schedule. The design of the combustor building housing the CFBC Facility has been completed. Second, according to discussions conducted at the project kick-off meeting held on January 13, 2004 at the National Energy Technology Laboratory (NETL) and additional comments from various experts, some modifications have been made to the draft design of the CFBC Facility. Third, the design calculations for the CFBC Facility have been completed during this period. These calculations include hydrodynamics, mass balance, energy balance, heat transfer, thermal expansion, and strength. Fourth, experiments for a laboratory-scale simulated fluidized-bed combustion (FBC) facility have been prepared. After this laboratory-scale FBC facility was set up in the last quarter, a Mass Flow Controller (MFC) was ordered to control the air flow into this FBC facility, and a mini-glass screw feeder with rotation speed controller has been installed to control the fuel feed rate into this facility. At the same time, the refuse-derived fuel (RDF) has been collected. Literature on the formation of pollutants, such as nitrogen oxides (NO_x), sulfur oxides (SO_x), and organic compounds, from the combustion and pyrolysis of biomass and refuse-derived fuels (RDF) with high sulfur coal has been reviewed. Finally, the outline of work needed to be conducted in the next quarter is introduced briefly.

2. EXPERIMENTAL

2.1. *Construction of the New Combustion Laboratory*

In this quarter, the renovation of the new Combustion Laboratory and the construction of the CFBC Facility building have progressed greatly. Accomplishments include:

- ◆ Determination of the foot-print of the main components of the CFBC Facility, such as:
 - ❑ Riser
 - ❑ Downcomer
 - ❑ Fuel/Sorbent Bunkers
 - ❑ Primary & Secondary Cyclones
 - ❑ Primary Combustion Fans
 - ❑ Electrostatic Precipitator (ESP)
 - ❑ Induced Draft Fan
 - ❑ Internal Coolant Loop, including coolant pump
 - ❑ Heat Exchangers
 - ❑ External Coolant Loop, including coolant pump
 - ❑ Outside Heat Rejection Unit (Cooling Tower)
 - ❑ Height of the Riser and its elevation in the Combustor Building
 - ❑ Weight resulting from the Riser, Downcomer, as well as, the Primary and Secondary Cyclones
- ◆ Establishment of floor space allocation for Combustion Laboratory and Combustor building, including height of Combustor building.
- ◆ Establishment of heat rejection facility size and location, operating temperatures and tentative design type.
- ◆ Establishment of the size of utility services, such as:
 - ❑ Electric power
 - ❑ Natural gas
 - ❑ Water supply and sewer
 - ❑ Compressed air
 - ❑ Standby Generator Capacity
- ◆ Establishment of layout for fuel/bed material preparation and handling facility.

- ◆ Establishment of design for exhaust ventilation and heating, ventilation, and air conditioning (HVAC) requirements for Combustion Laboratory and Combustor Building.
- ◆ Establishment of the layout for control room facility.

2.2. Design Calculations of the 0.6 MW_{th} CFBC Facility

To make accurate calculations, the CFBC facility was divided into five sections to conduct the design calculations. These sections are dense zone, dilute zone, primary and secondary cyclones, solid recirculation loop, and tail section. Due to its long length, the dilute zone was divided into two subsections for design calculations. The calculations in each section cover solid and gaseous mass balances, energy balance, and heat transfer. The calculations have been performed to understand the hydrodynamic characteristics of the primary and secondary cyclones. Finally, the strength of the stainless steel pipe and thermal expansion at high temperature have been estimated.

2.2.1. Mass Balance Calculation

Coal, limestone, and air are fed into the furnace of the CFBC. The flue gas, ash, calcium sulfate (CaSO₄), and other calcium-based compounds are generated through a series of chemical reactions. Applying the mass conservation principle to the solid and gas phases in each section of the CFBC Facility, the calculated results of mass balance were obtained and listed in Table 1.

Table 1. Summary of Mass Balance Calculations for Each Section of the CFBC Facility.

Item	Unit	Inlet	Outlet
1. Dense zone			
Coal (Ash content = 7.82%)	lb/h	175.74	61.51
Limestone (calcium carbonate (CaCO ₃) content in limestone is 85% by weight)	lb/h	64.61	22.61
Ash solid	lb/h	5272.26	5285.91
Air feed	sft ³ /h	15670.48	
Flue gas	sft ³ /h		16964.05
Discharged solid	lb/h		31.85

2. Dilute zone (1 st subsection)			
Coal	lb/h	61.51	17.57
Limestone	lb/h	22.61	6.45
Ash solid	lb/h	5285.91	5303.41
Air feed	sft ³ /h	6027.11	
Flue gas	sft ³ /h	16964.05	23488.68
3. Dilute zone (2 nd subsection)			
Coal	lb/h	17.57	
Limestone	lb/h	6.45	
Ash solid	lb/h	5303.41	5310.41
Air feed	sft ³ /h	2410.84	
Flue gas	ft ³ /h	23488.68	26098.54
4. Primary cyclone			
Solid	lb/h	5310.41	531.04
Separated solid	lb/h		4779.37
Flue gas	sft ³ /h	26098.41	27304.74
5. Secondary cyclone			
Solid	lb/h	531.04	37.17
Separated solid	lb/h		493.87
Flue gas	sft ³ /h	27304.74	27304.74
6. Solid recirculation loop			
Solid	lb/h	5273.24	5273.24
Air	sft ³ /h	1206.33	1206.33
7. Tail section			
Solid	lb/h	37.17	
Captured solid	lb/h		37.17
Flue gas	sft ³ /h	27304.74	27304.74

Note: In mass balance calculations, the gas leakages along the flue gas duct are ignored. It is assumed coal is burned completely in the furnace of the CFBC facility, and limestone is consumed totally in the furnace of the CFBC facility. Coal and limestone entering the dilute zone stay in their original feeding states. The electrostatic precipitator (ESP) in the tail section is assumed to have 100% separation efficiency.

2.2.2. Energy Balance Calculations

Based on mass balance calculations, the energy balance has been computed for each section by applying the energy conservation principle. After the heat losses from the outside surface have been estimated for each section, all physical heat carried by solids (coal, limestone, ash, and spent materials) and gases (air and flue gas) and chemical heat (coal heat) have been computed one by one at the inlet and outlet of each section, then the energy balances have been set up for each sections. The summary of the energy balance calculated results are listed in Table 2.

Table 2. Summary of Energy Balance Calculations for Each Section of the CFBC Facility.

Item	Unit	Inlet	Outlet
1. Dense zone			
Coal heat	Btu/s	569.1	199.2
Sensible heat of recycling solids	Btu/s	418.4	526.7
Sensible heat of produced gases	Btu/s	3.9(A)	163.3(FG)
Heat loss from outside surface	Btu/s		1.7
Sensible heat of discharged solid	Btu/s		2.7
Heat absorbed by heat exchanger	Btu/s		97.82
2. Dilute zone (1 st subsection)			
Coal heat	Btu/s	199.2	56.9
Sensible heat of recycling solids	Btu/s	526.7	505.4
Sensible heat of gases	Btu/s	163.3(FG)+1.5(A)	218.8(FG)
Heat loss from outside surface	Btu/s		5.8
Heat absorbed by heat exchanger	Btu/s		103.6

3. Dilute zone (2 nd subsection)			
Coal heat	Btu/s	56.9	
Sensible heat of solids	Btu/s	505.4	503.9
Sensible heat of gases	Btu/s	218.8(FG)+0.6(A)	243.1(FG)
Heat loss from outside surface	Btu/s		6.1
Heat absorbed by heat exchanger	Btu/s		28.7
4. Primary cyclone			
Sensible heat of solids	Btu/s	503.9	453.6
Sensible heat of gases	Btu/s	243.1(FG)	187.3(FG)
Heat loss from outside surface	Btu/s		2.3
Heat absorbed by heat exchanger	Btu/s		103.9
5. Secondary cyclone			
Sensible heat of solids	Btu/s	45.4	42.0
Sensible heat of gases	Btu/s	187.3(FG)	173.3(FG)
Heat loss from outside surface	Btu/s		1.5
Heat absorbed by heat exchanger	Btu/s		15.5
6. Standpipe section			
Sensible heat of solids	Btu/s	447.2	417.5
Sensible heat of air	Btu/s	0.3(A)	8.8(A)
Heat loss from outside surface	Btu/s		5.8
Heat absorbed by heat exchanger	Btu/s		15.4

Note: A represents Air, and FG represents Flue Gas.

2.2.3. Heat Transfer Calculations

In order to control the bed temperature and make the bed temperature distribution uniform along the bed height, the heat transfer exchange surfaces need to be arranged along the bed height, cyclones, and the solid recirculation loop. The purpose of these heat transfer

calculations is to estimate the heat transfer coefficient between the bed and the heat exchange surface, further to determine the areas of heat exchange surfaces. The convective and radiative heat transfers have been taken into account in these calculations. Based on the (theory of) theoretical fluid dynamic structure inside the CFB's riser, the solid-gas flow consists of two phases: one phase that contains particle aggregations and gas is called the cluster phase; another phase is named the dispersion phase containing dispersed particles and gas. Therefore, both convective and radiative heat transfer coefficients received contributions from these two phases. Table 3 shows the results of heat transfer calculations for each section.

Table 3. Summary of Heat Transfer Calculations for Each Section of the CFBC Facility.

	Heat transfer coefficient	Heat exchange surface area	Ratio of absorbed heat by this section to the CFBC's input
Unit	But/ft ² .h.°F	ft ²	%
Dense zone	37.6	8.01	17.2
Dilute zone (1 st subsection)	33.4	9.70	18.2
Dilute zone (2 nd subsection)	32.4	2.75	5.0
Primary cyclone	19.0	17.5	18.3
Secondary cyclone	12.4	4.2	2.7
Standpipe section	6.4	7.9	2.7
Tail section	7.3	95.8	27.1

2.2.4. Design Calculation of Primary and Secondary Cyclones

The solid separation apparatus plays an important role in the CFBC Facility. Its separation efficiency impacts the solid recirculation ratio directly, and in turn effects the combustion process, heat transfer, and the utilization efficiency of limestone further. Therefore, its design should be optimized in consideration of present and future projects. Since its solid recirculation ratio is 30, this CFBC Facility must possess a high-efficiency solid separation device. To reach the high separation efficiency required, two-stage cyclones are used to separate solids from the flue gas stream. Table 4 gives the structure data and operation parameters of these two cyclones.

Table 4. Design Calculations for Primary and Secondary Cyclones.

Item	Unit	Primary Cyclone	Secondary Cyclone
Inlet velocity	ft/s	95.6	89.0
Inside diameter	in	23.5	19.5
Height of straight section	in	48	40
Total height	in	96	80
Inlet width	in	4.75	4.75
Inlet height	in	9.25	9.25
Outlet diameter	in	12	10.25
Dipleg diameter	in	5.047	3.548
Separation efficiency	%	90	93
Pressure drop	lb/in ²	0.0249	0.0297

2.2.5. Estimation of Stainless Steel Pipe's Strength and Thermal Expansion

The strength and thermal expansion have been some of our most important concerns for using type 310 stainless steel to construct the CFBC Facility. Therefore, the stress and thermal expansion of type 310 stainless steel pipes at the high temperature have been estimated carefully. Table 5 gives the calculated results of strength and thermal expansion.

Table 5. Summary of Strength and Thermal Expansion Calculations

Item	Unit	Bottom Section	Middle Section	Top Section
Length	ft	24	20	20
Estimated weight	lb	2585	2690	2280
Thermal expansion	in	4.32	3.6	3.6
Max. tensile stress	ksi	0.141	0.146	0.124
310SS Yield strength	ksi	16.10 at 1600°F		

All these calculations are based on 100% load of the CFBC Facility. The same calculations have been completed based on 50% load of CFBC Facility. The detailed calculation procedures and results are listed in a total 136-page file, which is available on request.

2.3. Design and Drawing of the 0.6 MW_{th} CFBC Facility

2.3.1. Design Modifications of the CFBC Facility

Based on the concept design work done in the first quarter (September 15, 2003 – December 31, 2003), the feedback from the project kick-off meeting held on January 13, 2004, and suggestions and comments collected from some experts around the world, the following modifications have been made to the CFBC Facility.

- ◆ Electric power will be used in place of natural gas to heat up this CFBC Facility during the start-up period. Increased safety is the primary reason for this decision, because natural gas has an explosive possibility if mishandled, requiring much careful attention for use in the laboratory. Additionally, a natural gas burner could overheat some local areas on the air distributor or inside the windbox. Compared with natural gas, electric power can avoid these disadvantages. However, an electrically powered preheater will take more time to heat up the CFBC Facility to the desired ignition temperature than natural gas.
- ◆ A declined-surface air distributor has been designed, providing a smooth surface to aid discharge of solids from the bottom of the CFBC.
- ◆ To reduce construction cost, the multi-channel heat exchange surface has been replaced by a water jacket.
- ◆ The thermal expansion joints have been designed carefully in order to avoid impairment of function due to blockage by solids accumulating in the gap between the outside pipe and the outside flexible pipe or bellows.

All these modifications will be introduced in detail in the RESULTS AND DISCUSSION section.

2.3.2. Drawings of Assembly Parts for the CFBC Facility

After the concept design of the CFBC Facility was finalized and the design calculations were completed, the detailed front-view, top-view at different cross sections, and elevation drawings of CFBC Facility were prepared. The coal and limestone feeder and bunkers, heat exchange surfaces, secondary air nozzles, sample ports and sight glasses, and all platforms have been shown on these drawings. Next, the focus shifted to designing all the CFBC sub-assembly parts that will make up the CFBC Facility. These assembly parts are the windbox section including the air distributor, bubble caps, and solid discharge tube, a total of 13 segments (I.D.

15.15" and 12") including a reducer segment for the riser, a thermal expansion joint, primary and secondary cyclones, a total of 9 segments for the solid recirculation loop, and a loop seal. All these drawings are available on request.

3. RESULTS AND DISCUSSION

3.1. Renovation of the Space for the New Combustion Lab

Low initial cost estimates for the Combustor building and the Combustion Laboratory renovation by the project architects led to the decision to include more facilities and laboratory furnishings in the construction and renovation project. As detailed design specifications and architectural drawings were completed, a more accurate estimate of construction and renovation costs was prepared. These latter estimates were found to be greater than the total funds available for the construction and renovation project. As a result, certain facilities and furnishing were either reduced, eliminated, or made a part of an "Add Alternate" bid specification. Design specifications and architectural drawings were then completed with the estimated cost in line with the funds available. At this time, the project architects have submitted drawings and estimates to Western Kentucky University's Construction Management group and the "finished documents" are expected to be completed by April 2, 2004. Therefore, advertisement to bid would be published beginning on or before April 5, 2004. The bidding period will be open for 30 days. From this, it would be expected that evaluation of bids would commence on May 5, 2004, with notice of awards to begin on or about May 20, 2004. Construction should commence by June 21, 2004.

A couple of other factors that have accounted for project delays pertains to the Combustor building. One factor was to increase the total length of the Combustor system, in order to collect the most useful research data in view of recently released information regarding other projects. This necessitated an increase in the overall height of the Combustor building, with an associated increase in architectural design time and building cost. A second factor was subsurface investigations that revealed soil and other underground features that required the foundation for this building be significantly strengthened. This also added design time and cost.

3.2. Modification of the Air Distribution System

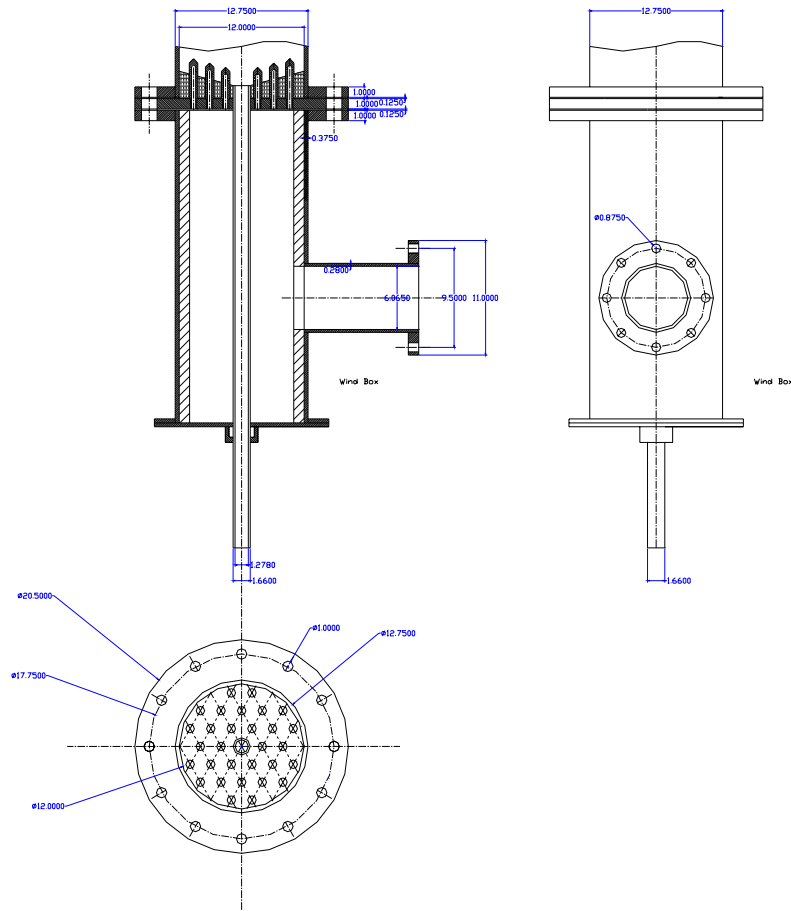


Figure 1. The decline-surface air distribution system.

At the project kick-off meeting, the design of the air distribution system was discussed. Dr. Mei of the National Energy Technology Laboratory questioned whether waste solids could be discharged smoothly from the bottom of the dense zone. The use a decline air distributor was suggested. Considering the difficulty in manufacturing a decline distributor with such a small diameter, different heights of bubble caps are employed to reach the decline effect of the air distributor surface. Figure 1 shows the detailed structure of this air distributor. There are a total 30 bubble caps arranged in 3 circles on the air distributor. The inner circle consists of 6 bubble caps 4-inches in height, the middle circle consists of 12 bubble caps 4.4-inches in height, and the outer circle has 12 bubble caps with 4.8-inches in height. Fire clay is filled into the gaps between the bubble caps, thus establishing the desired a decline surface just beneath the small holes of the

bubble caps. Therefore, this structure plays the same role as the cone air distributor, and simplifies the manufacturing process.

3.3. Consideration of Thermal Expansion

Thermal expansion has been a source of concern since type 310 stainless steel 310 which was selected for use in this CFBC facility, has a high thermal expansion property. As shown in Table 5, the total thermal expansion of the CFBC's riser reaches almost 1ft. Although the CFBC's riser has been divided into 3 sections, each section's thermal expansion still is over 3 inches. As discussed in the quarterly technical progress report for the period September – December 2003, the bottom and middle sections are to be supported by structural elements of the Combustor building at the 4th floor level. The top section is to be supported by structural elements of the building at the 8th floor level in order to handle the thermal expansion issue more easily. Supporting the riser at two locations reduces thermal expansion problems with the lower section as it can expand downward without interference. A special-design thermal expansion joint (Figure 2) is to be arranged between the middle and top sections to compensate for the upward and downward expansion from middle and top section, respectively. Since the length of the outside pipe (I.D. 15.25") is 17", then the maximum accumulation height of solids in the gap between the outside pipe and outside flexible pipe of the thermal expansion joint is 17". Second, six holes (I.D. 0.75") are distributed uniformly on the wall of the outside pipe near the lower flange, so the solids accumulated in that gap could flow back into the bed. Finally, compressed air is provided to purge that gap in order to make the expansion joint function very well. To assure that this thermal expansion joint will work well at the high temperature, it also is made of type 310 stainless steel. It is designed to accommodate thermal expansion of close to 15", this being much greater than the required expansion length (7.2") predicted by our thermal expansion calculation.

3.4. Structure of Heat Exchange Surface

In the original design, the heat exchange surface consisted of many vertical stainless steel channels welded to the outside surface of the CFBC's riser pipes. Water flowing inside the channels absorbs the heat from the CFBC, thus controlling the bed temperature. Initially, this design was proposed to provide a uniform bed temperature with flexible control, because these channels could be divided into three groups. According to the variation of bed temperature, one,

two, or even three groups can be fed with water. Therefore, the heat needed to be absorbed from the combustor can be controlled accurately and easily. However, this multi-channel structure requires a lot of welding work with a large increase in the fabrication cost. In the latest design,

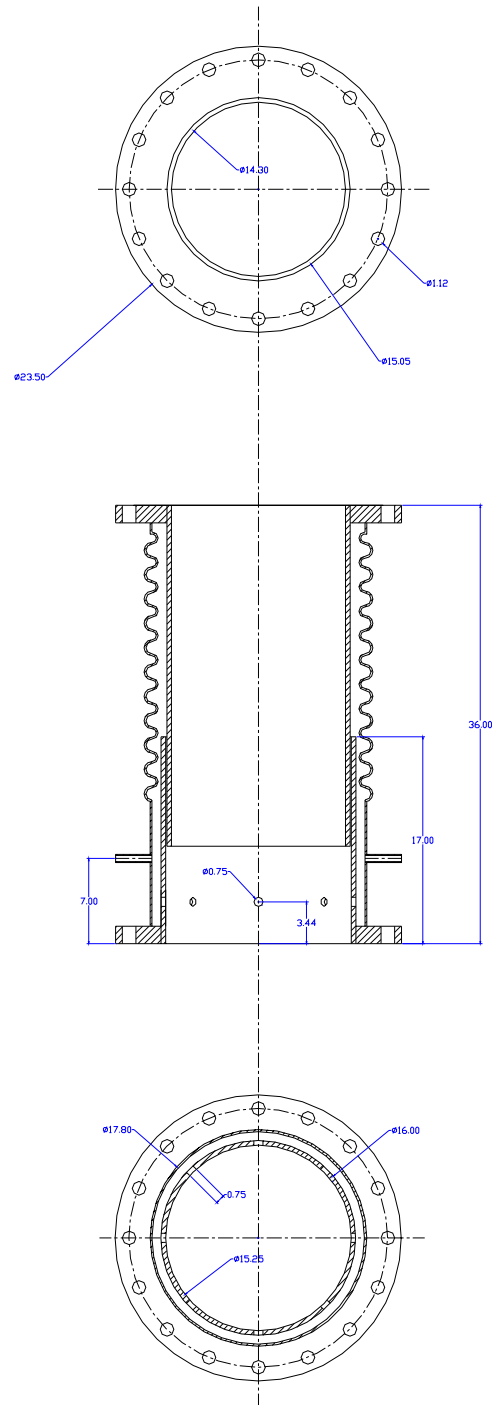


Figure 2. The structure of the thermal expansion joint.

water jackets were chosen to replace the multi-channel structure in order to reduce the fabrication cost. To control the heat absorbed from the CFBC Facility with flexibility, the water jacket is divided into several sections arranged along the bed height. Shown in Figure 3 is one segment of CFBC Facility's riser with water jacket in place. According to the load and the bed temperature required, water can be supplied to part or to all of the water jackets. Therefore, the heat absorbed from the CFBC Facility can be adjusted according to the requirements. Of course, the uniformity of the bed temperature controlled by this type of construction is not as good as that by multi-channel construction.

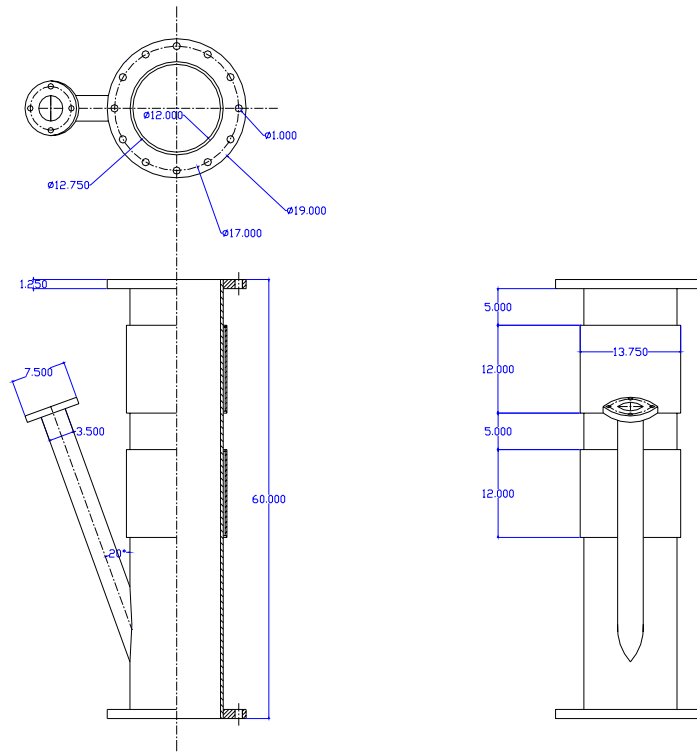


Figure 3. Heat exchange surface arranged on the riser of the CFBC facility.

3.5. Fundamental Research with a Laboratory-Scale Simulated Fluidized Bed Facility.

Preparation work has been completed on the laboratory-scale simulated fluidized-bed combustion (FBC) facility in order to do some fundamental research. A Mass Flow Controller (MFC) has been ordered and installed on the FBC facility to control and adjust the air flow rate entering this apparatus. A mini-glass screw feeder has been installed to supply the fuel (coal and RDF) into the combustor. A flue gas analyzer has been set up to analyze the gases components,

such as oxygen (O₂), carbon dioxide (CO₂), carbon monoxide (CO), NO_x, sulfur dioxide (SO₂), and hydrochloric acid (HCl). RDF to be burned in this experiment has been collected. Experimental work is continuing. Since the MFC manufacturer took four weeks to assemble the instrument, this work is behind schedule about a month. In the next quarter, this work will be accelerated so that the experimental data can be released in the next quarterly technical progress report.

4. CONCLUSIONS

In the second quarter of this project, progress on the following tasks was made:

- ◆ Renovation of the Combustion Laboratory and construction of Combustor Building progressing on schedule.
- ◆ After the mass balance, energy balance, and heat transfer calculations for each section of the CFBC Facility were completed, the overall design for the CFBC Facility was finalized. Modifications were based on the calculation results and the information collected from the project kick-off meeting held on January 13, 2004 and suggestions from some experts from around the world.
- ◆ All assembly parts of the CFBC Facility have been designed and drawn in detail. This work has laid a solid foundation for developing specifications for the fabrication of the component parts in the next stage.
- ◆ Preparation work was done for some fundamental research on a simulated FBC system. Experimental work on this FBC apparatus has started and is moving forward smoothly.

5. FUTURE WORK

In the next quarter, the following tasks will be the focus of our efforts:

- ✦ Continue construction of the Combustion Laboratory and Combustor Building.
- ✦ Construction contracts for both projects will be awarded and the renovation of the space for the Combustion Laboratory will begin. Construction of the new Combustor Building will start in the next quarter. The internal arrangement in this

building will be considered, and the platform used for supporting the CFBC Facility will be designed in detail.

- ✦ Drawings of component parts will be completed. Based on the drawings of the CFBC Facility and key assembly parts, all component parts of the CFBC Facility will be designed and drawn in detail in order for fabrication of these parts to proceed. Due to the complexity of the CFBC Facility, the number of parts in the CFBC facility is huge, and this work will be a time-consuming process.
- ✦ Contracts to the fabricators and purchase orders to the suppliers of component parts for CFBC Facility will be completed. After all drawings of the component parts of the CFBC facility are completed, component parts and fabrications will be bid by suppliers. Working together with these suppliers, satisfactory design solutions will be developed.
- ✦ Continue experiments on the laboratory-scale simulated FBC facility. The following experiments will be finished on a laboratory-scale simulated FBC facility in the next quarter:
 - ❖ Continue to investigate conditions for oxidation of HCl to chlorine (Cl_2) (Deacon reaction) in a flue gas atmosphere. The experimental data will be analyzed based on the chemical reaction kinetics.
 - ❖ Continue to study reaction conditions for copper oxide (CuO), O_2 , and SO_2 to form copper sulfate (CuSO_4).
 - ❖ A paper will be prepared to report the findings and results obtained from these fundamental studies conducted in this period.

MILESTONES

Base on the current progress, the milestones scheduled previously for this project have been modified as shown in Figure 4.

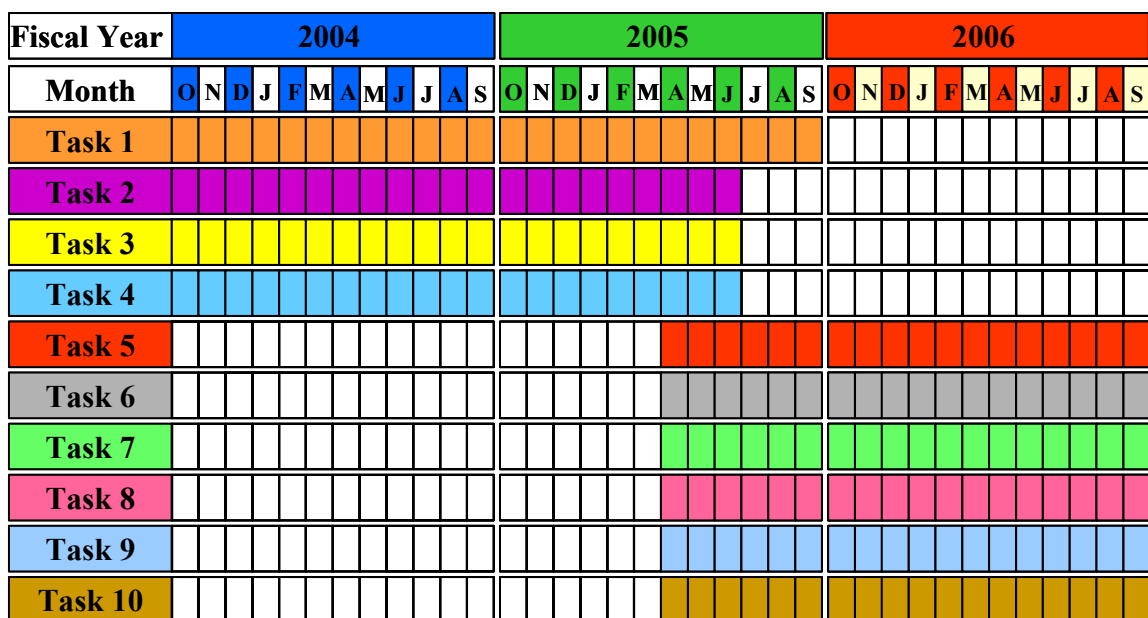


Figure 4. Modified milestones based on the current progress

ACKNOWLEDGEMENTS

The authors thank Professor Guangxi Yue from the Tsinghua University in China. Professor Yue has a lot of experience in designing and tuning CFBC boilers in China. During a visit to the Combustion Laboratory on January 26 to 29, 2004, Professor Yue discussed the CFBC design. As a result of these discussions, suggestions and comments provided by Professor Yue have been most helpful and valuable for designing the CFBC Facility and operating the CFBC Facility in the future.

ACRONYMS AND ABBREVIATIONS

CFBC	Circulating Fluidized-Bed Combustion
DOE	U.S. Department of Energy
ECTL	Environmental Control Technology Laboratory
ESP	Electrostatic Precipitator
FBC	Fluidized-Bed Combustion
HVAC	Heating, Ventilation, and Air Conditioning.
I.D.	Inside Diameter

MFC	Mass Flow Controller
NETL	National Energy Technology Laboratory
NO _x	Nitrogen Oxides
O.D.	Outside Diameter
RDF	Refuse-Derived Fuel
SO ₂	Sulfur Dioxide
SO _x	Sulfur Oxides
U.S.	United States

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